Application Note

Embedded Design Techniques for Developing Cost-Effective Communications

Introduction

As embedded designs become more intelligent and connected, the communication links of these devices turn out to be increasingly important. At the same time, end user constraints around portability, longer battery life, and lower prices make it even more critical to find a cost-effective means for providing reliable communication.

Wired interfaces, such as USB and Ethernet, are common in many embedded designs and are being pushed to the limits of the standards in many applications. While the appeal of portable battery-operated devices drive the need for more power-efficient wireless connectivity. This application note describes three tangible applications utilizing specific measurement techniques that enable you to quickly and efficiently deliver cost-effective communication in your embedded designs.

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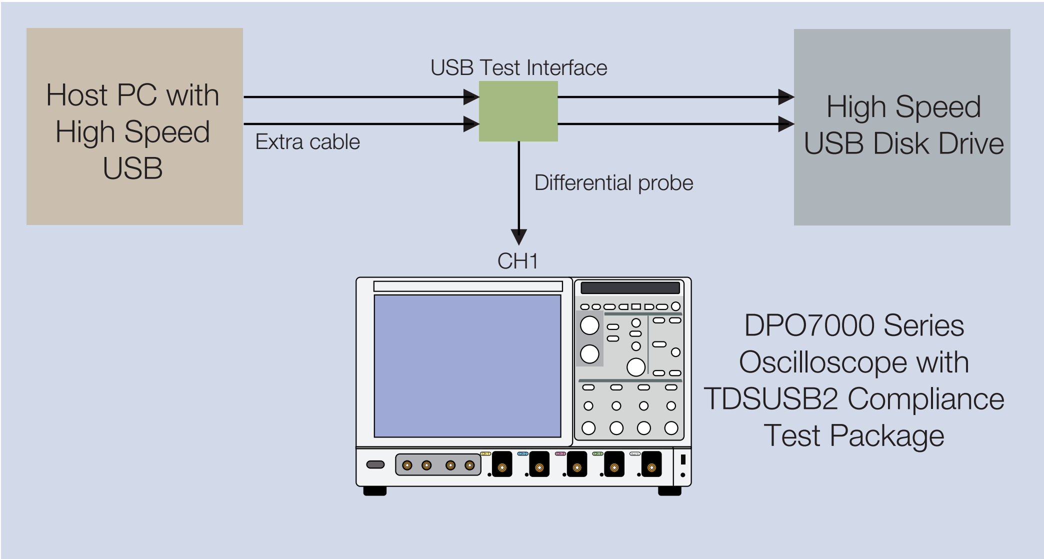

Figure 1.1. Block diagram of High Speed USB performance test.

Application 1. USB Interface Performance Evaluation

The USB interface is used in a very wide range of computer peripheral and embedded applications. It is critical to verify the performance of USB devices and any related cabling and connections. The DPO7000 Series oscilloscope offers the bandwidth required to measure the operation of the high speed USB, which nominally supports 480 Mbits per second. Using a USB interface board and the TDSUSB2 Compliance Test Package software, we will be able to simplify the characterization and compliance of these devices.

The most common use of the TDSUSB2 Compliance Test Package is to determine how products designed under the USB2.0 compliance specifications will perform in a certification test. USB2.0 logo compliance certification is governed by the USB Integrators Forum (USB-IF) in order to achieve wide-spread compatibility of USB products. Only compliance certification conducted and approved by USB-IF agents is valid for USB Logo compliance. Tektronix is a member of the USB-IF and supports and encourages all USB2.0 products to earn logo compliance from the USB-IF.

The objective of this example is to understand the typical degradation of the USB signal due to extended cable length. The same analysis could be applied to other situations such as unknown connectors, different types of cables, and the effect of hubs and other USB devices. The nominal limit to the length of a USB cable is 5 meters, but often this is not long enough for convenience. In this example we will begin by measuring the signal quality with the nominal 5 meter cable length. Then we will add extra cable length between the PC host and the USB disk drive used for this demonstration to see what the effect will be on the signal quality if the additional cable length is needed for a particular installation.

Figure 1.1 shows the connection of the host PC, the USB disk drive and the DPO7000 Series oscilloscope. The connection is through a custom USB test interface, and the extra length of cable is added between the host PC and the interface. For high speed USB, the oscilloscope needs a bandwidth of at least 2.5 GHz to allow accurate measurement of the signal details at the 480 Mbits per second data rate. Since USB signaling is differential, we have selected a differential probe which has a bandwidth of 3.5 GHz. The analysis of the USB signal is performed the by TDSUSB2 software running on the oscilloscope.

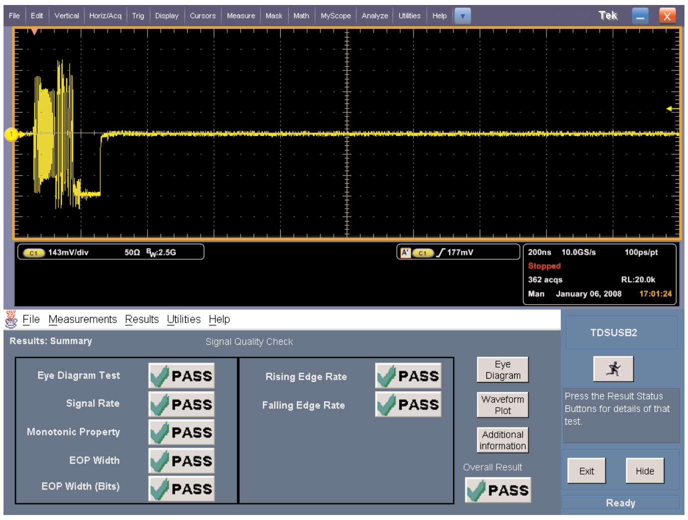

Figure 1.2. Waveform and signal quality report for the basic 5 meter USB cable in high speed operation.

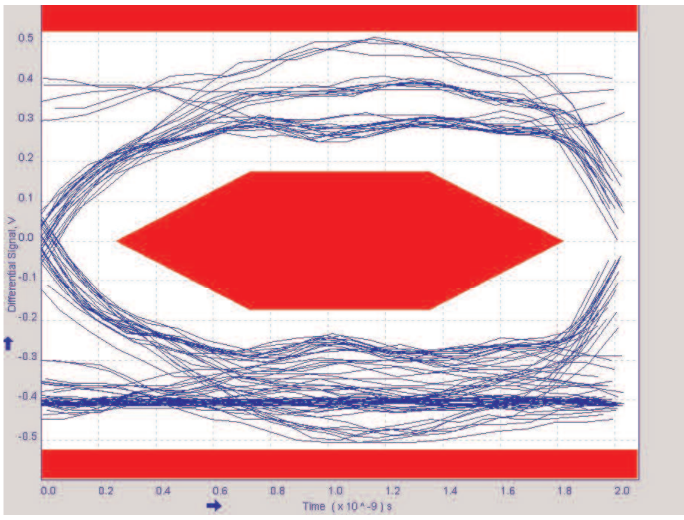

Figure 1.3. Eye diagram of high speed USB signal with 5 meters of cable.

In Figure 1.2 we see the results of the full set of USB compliance tests on a transfer using no more than the specified 5 meters of cable. We are testing the high speed (480 Mbits per second) version of USB since this is becoming increasingly common and is the most difficult to assure performance. The six tests listed above are performed in just a few seconds by the TDSUSB2 compliance software running on the oscilloscope. This screen enables you to quickly assess the standard USB compliance test results. While missing some of these parameters by a small amount may still allow the communications to be successful, these tests indicate whether the USB data transfers will be reliable and fully compliant.

Figure 1.3 is the eye diagram for the maximum allowed cable length of 5 meters. To view this display, you simply click the “Eye Diagram” button seen on the summary screen in Figure 1.2. The eye diagram shows the relative timing of the signal over a number of bit periods. Notice the open pattern of the signals which stay away from the violation area indicated by the red block. This is commonly referred to as a mask test. The red areas define regions which the signal should not cross if the signal is operating correctly. Signals that cross into the red areas, thus closing the “eye” in the pattern, have incorrect amplitude or timing. These characteristics indicate that the circuitry receiving the signal may not be able to decode it correctly.

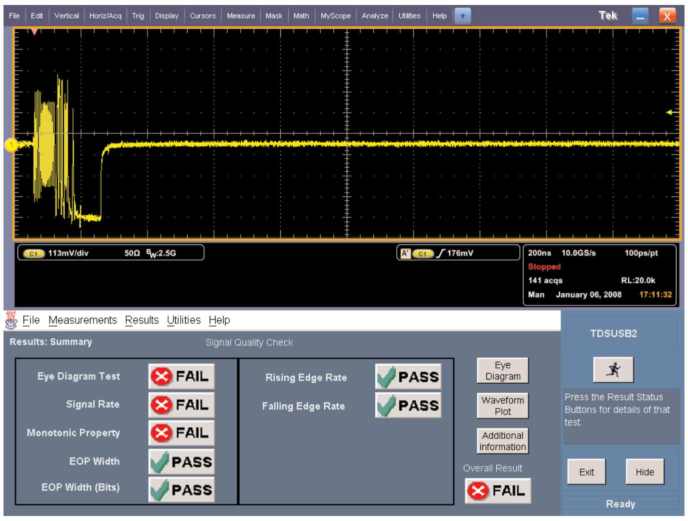

Figure 1.4. Waveform and signal quality report for the extended 10 meter USB cable in high speed operation.

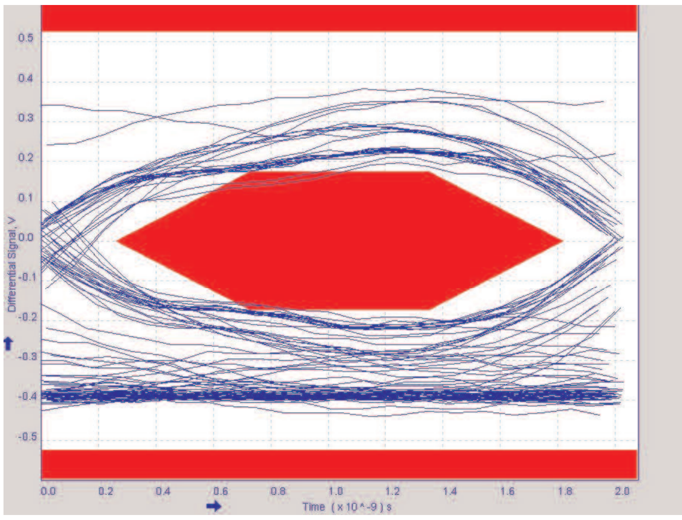

Figure 1.5. Eye diagram of high speed USB signal with 10 meters of cable.

For many installations, it would be desirable to connect to a USB disk drive, printer, or other device across a room or in some convenient location. Also, it is sometimes necessary to extend the cable to run around the edge of the room, over a doorway, or overhead. In these situations, a cable longer than the 5 meter limit would be required. However, as seen in Figure 1.4, when the cable is extended to double the specified length a number of the compliance tests fail. Note, however, that the oscilloscope waveform has not changed very much, so just using the oscilloscope trace for this determination would not be adequate.

In Figure 1.5, the eye diagram with the 10 meter cable shows substantial degradation of the signal with many of the bit transitions crossing into the red mask region. Overall the "eye" is much more closed than in a compliant pattern. The combination of failed tests, along with multiple violations of the eye pattern, tells us that this cable length will not provide reliable or potentially usable data communications.

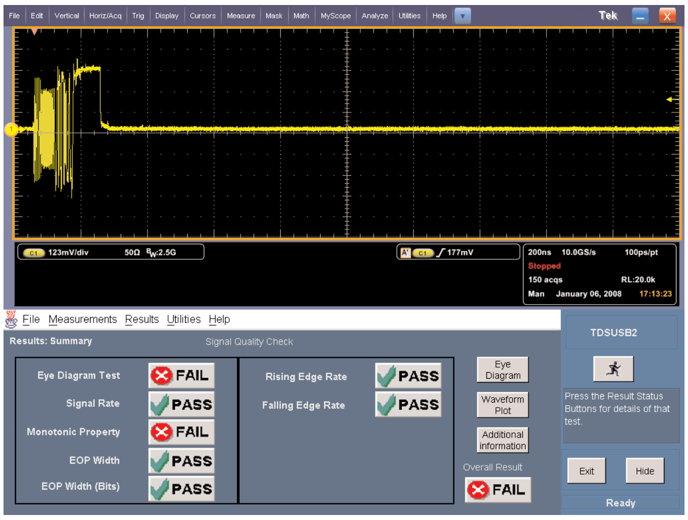

Figure 1.6. Waveform and signal quality report for the extended 7.5 meter USB cable in high speed operation.

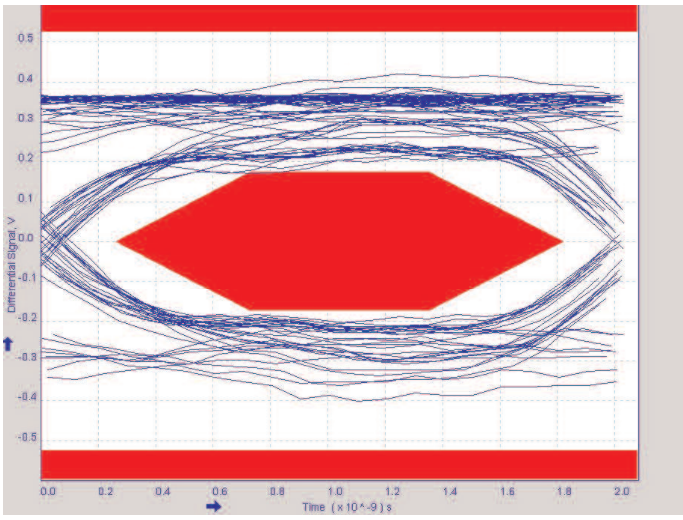

Figure 1.7. Eye diagram of high speed USB signal with 7.5 meters of cable.

Since doubling the cable length to 10 meters was unsuccessful, we then proceed with evaluating only a 50% increase in the length of the cable to 7.5 meters, as shown in Figure 1.6. Note that only two of the tests fail now. Also note that the signal trace is not distinguishable from the other two traces. To get a better idea of how far this signal is from acceptable, we will take a closer look at its eye pattern.

In Figure 1.7, the eye diagram shows that the test is only barely failing. With a cable length of 7.5 meters, a single violation can be seen in the center of the mask, near the top left, indicating the eye is only slightly beginning to close. Therefore it is possible that this length of this cable may work acceptably for our application, even though it is longer than the approved limit of 5 meters.

We have used the TDSUSB2 Compliance Test Package running on the DPO7000 Series oscilloscope to demonstrate the ability to quickly and confidently evaluate USB communications. We saw that there was significant degradation of the signal with only a modest increase in cable length over the standard. If a longer cable is required, a cable extender should be considered, or a longer range connection such as Ethernet used.

While the example of extending the cable is a simple one, the capability can be critical to assure that the USB device being developed or tested is compliant with the standards. The eye diagram and numerical reports allow evaluation of the margin by which a device or connection scheme passes or fails the specification. This capability of the DPO7000 Series oscilloscope could be applied to a wide range of USB devices and connection scenarios. For developers of high speed USB systems, this test capability is especially critical to assuring that products will work reliably in the field.

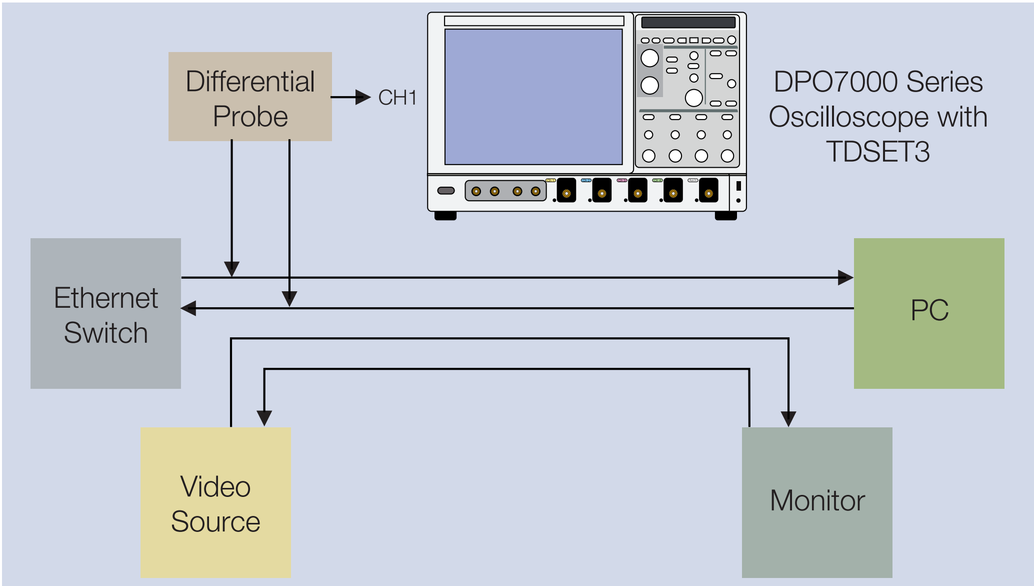

Figure 2.1. Block diagram of test setup.

Application 2. Ethernet Interference Analysis

Standard 10/100 base T Ethernet uses only two of the four twisted pairs in category 5 or category 6 cabling. A number of applications have been proposed to exploit these unused wires and extract additional value from the existing cabling. In this example, we will use the TDSET3 Ethernet Compliance Test Software running on the DPO7000 Series oscilloscope to evaluate the effect of sharing the unused pairs of an Ethernet cable with a video signal. The challenge in this example is to determine if the video signal will degrade the Ethernet signal and impact the performance. The TDSET3 software is normally used to determine the compliance of an Ethernet device to the published standards. Looking at the raw signals on an oscilloscope will not necessarily indicate the impairments, so we will utilize the TDSET3 capabilities to get a comprehensive analysis of the effects. We will use the eye diagram display of the compliance software to observe what is happening to the Ethernet signal when the video signal is introduced at three different cable lengths.

Figure 2.1 is a block diagram of the test configuration used in this application. The Ethernet cable is split at the ends with two of the pairs connecting the Ethernet switch to the PC and the other two pairs carrying the video signal to the monitor. A high frequency differential oscilloscope probe is used to access the Ethernet signal from the Ethernet pairs of the cable when the video signal is present or removed from the adjacent pairs.

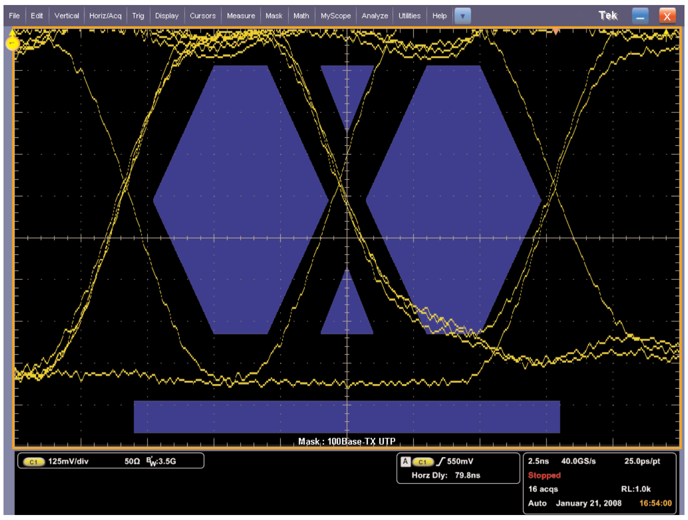

Figure 2.2. Eye diagram of signal with 0.3 meter of Ethernet cable and no video signal.

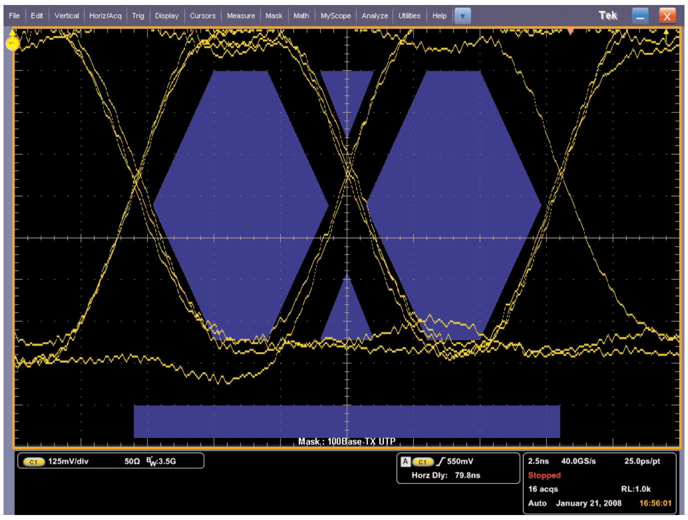

Figure 2.3. Eye diagram of signal with 0.3 meter of Ethernet cable and with the video signal.

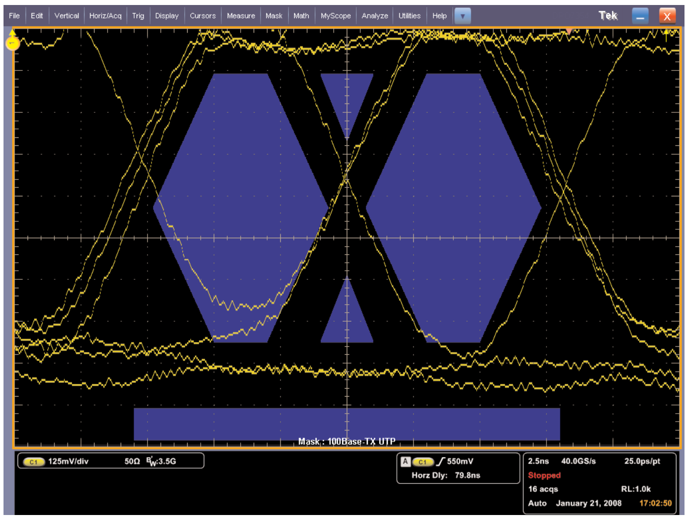

Figure 2.4. Eye diagram of signal with 10 meters of Ethernet cable and no video signal.

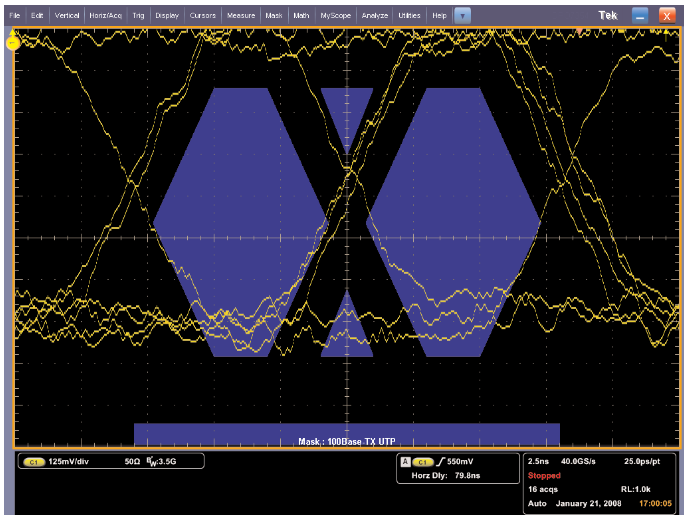

Figure 2.5. Eye diagram of signal with 10 meters of Ethernet cable and with the video signal.

In Figure 2.2, the eye diagram of the Ethernet signal is shown with a very short cable and no video signal present. The eye diagram shows the amplitude and phase transitions compared to a mask represented in the blue regions. The concept of the eye diagram is that there should be an open area (the eye) during these transitions. While there are signals crossing the blue area in one small portion of the diagram, there is very little distortion of this signal.

Figure 2.3 demonstrates that adding the video signal, even on a very short cable, shows some interference between the video and the Ethernet signals as the eye begins to close. The coupling is likely to be in the connectors as much as it is in this very short length of cable. This amount of coupling is very unlikely to cause any difficulty with the Ethernet signal.

Figure 2.4 shows the Ethernet signal on a longer cable but with the video signal removed. There is some further distortion in the Ethernet signal, but still not enough to cause any difficulty due to the cable length by itself.

However, when the video signal is added to this longer cable, there is more degradation of the Ethernet signal, as shown in Figure 2.5. Note that there is coverage of the bottom part of the hexagonal shapes in the center of the mask. Violations this significant may start to degrade performance of the Ethernet communications.

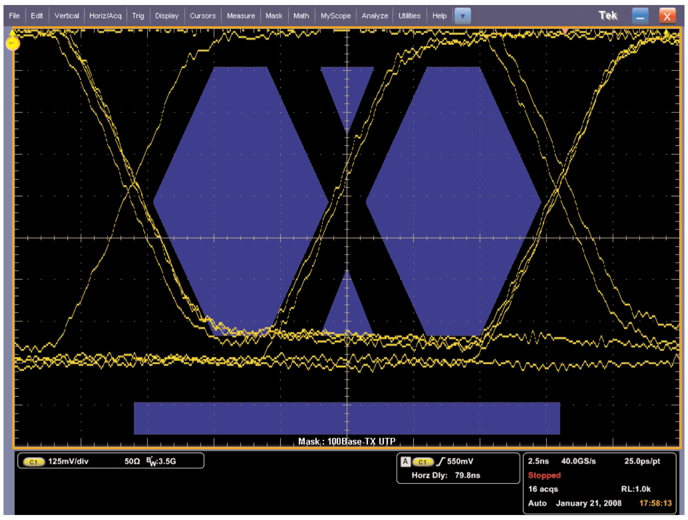

Figure 2.6. Eye diagram of signal with 50 meters of Ethernet cable and no video signal.

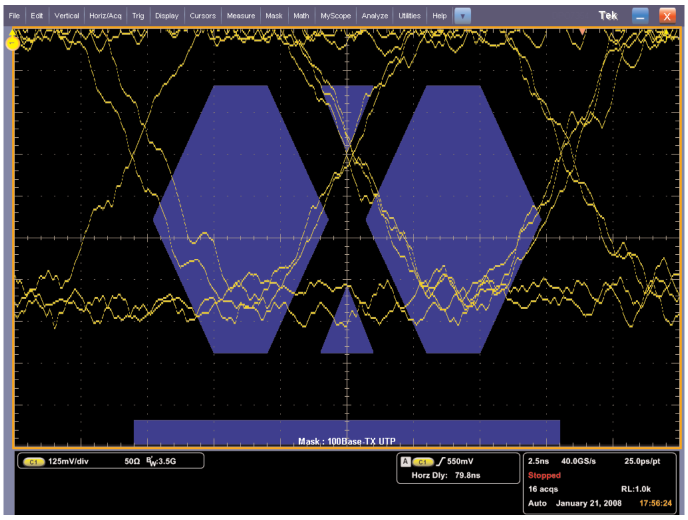

Figure 2.7. Eye diagram of signal with 50 meters of Ethernet cable and with the video signal.

In Figure 2.6 we can see that even a 50 meter cable with no video signal present has very small deviation from the desired eye pattern. Only a small part of the blue mask area is covered, so even at this cable length a good Ethernet communication is possible.

However, when the video signal is added to the 50 meter cable, we can see that the Ethernet signals cover a large part of the blue mask area shown in Figure 2.7. Also note how distorted the actual signals become as well. At this length, the video signal is very likely to interfere with the Ethernet communications unless the amplitude of the video signal is reduced.

In this example we have looked at the effects of carrying a video signal on the unused pairs of standard twisted pair Ethernet cable at varying lengths. While economically it is very attractive to get additional use from existing cable, we have discovered that some caution is needed. There is some coupling of the signal even with a very short Ethernet cable, but the signal degrades rapidly as the cable length is increased. This indicates that the video signal is coupling to the Ethernet signal in the cable, in addition to some coupling in the connectors. Based on this analysis, we have discovered that we may need to reduce the amplitude of the video signal for this application to be viable.

Using the TDSET3 Ethernet Compliance Test Software running on the DPO7000 Series oscilloscope, we were able to observe the detailed effects on the Ethernet signal with much more information. A standard oscilloscope trace without the software would have shown almost no difference with and without the video signal.

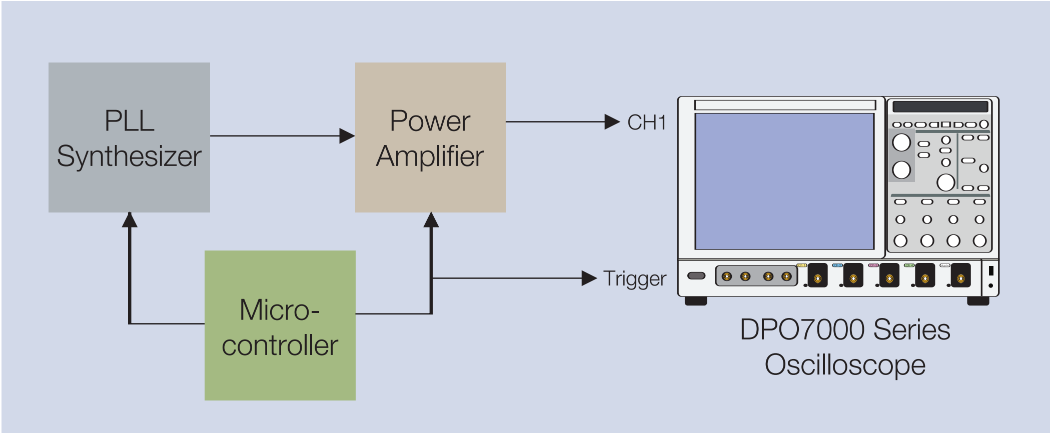

Figure 3.1. Block diagram of transmitter and oscilloscope.

Application 3. RF Performance Evaluation

In this example, we will evaluate the transient effect on a radio transmitter of turning on the output power amplifier. This transmitter requires extremely clean and stable output during the time that data is transmitted so the receiver can reliably decode the data. To help achieve that, the PLL synthesizer that generates the signal is turned on first and allowed to stabilize before the output power amplifier is turned on. Turning on the power amplifier causes some distortion of the signal, which can be seen in a spectrum display of the output signal. Using the Advanced Spectrum Analysis capability of the DPO7000 Series oscilloscope, we can observe the spectrum at a specific time with relation to a trigger signal. By taking spectrum readings at various time delays after the power is applied to the power amplifier, we can determine when the effects of startup have ended so the transmission of data can be started. The transmitter is battery powered, so the challenge here is to determine the shortest possible time to delay startup of the data from the transmitter in order to maximize the battery life.

Figure 3.1 shows the basic configuration of the system in which the synthesizer and the power amplifier are controlled by a microcontroller. The oscilloscope is triggered by the power control signal from the microcontroller and the signal is fed from the output of the power amplifier to the oscilloscope.

Figure 3.2 shows the spectrum taken at the startup of the radio frequency power amplifier. The signal from the power amplifier output (yellow trace) shows the amplitude of the output signal versus time varies as expected from a traditional oscilloscope trace. The control signal (violet trace) shows the turn on and the actual spectrum (orange trace) is also displayed as the signal amplitude versus frequency (the same as a standard spectrum analyzer display). The relatively wide peak in the spectrum indicates that there is frequency noise on the signal. This noise would prevent the receiver from correctly decoding a signal modulating this carrier. The variation shown on the amplitude output (yellow trace) would also impair the signal, so the receiver would not function correctly using this signal.

With a much longer delay we can see a stable signal in the spectrum display, as shown in Figure 3.3. We arbitrarily selected a delay of 100 milliseconds to assure that the signal had fully settled. Note the clean, steady amplifier output (yellow trace) and the very narrow spectrum (orange trace). This provides a reference for what we are looking for, but to conserve battery energy we want to use as short a delay as possible. The spectrum display must be as clean as this one to meet the stringent requirements of the receiver.

Figure 3.4 shows the spectrum taken 0.5 milliseconds after startup. This delay was selected because the amplitude seems to have settled at this time. However, there is still widening of the spectrum (orange trace) compared to what we saw at 100 milliseconds in Figure 3.3, so this is not enough time delay to start the data transmission. The widening of the trace indicates that there would still be enough noise on the signal to impair data reception at the receiver even though the signal trace (yellow) does not show any problem.

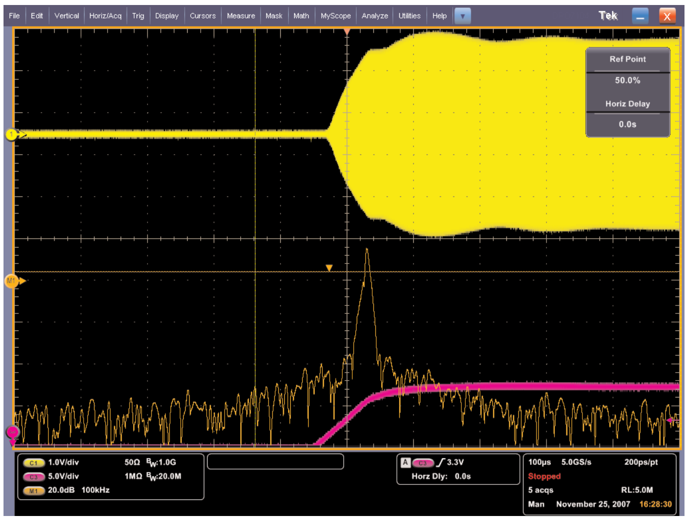

Figure 3.2. Signal and spectrum with no delay after power amplifier startup.

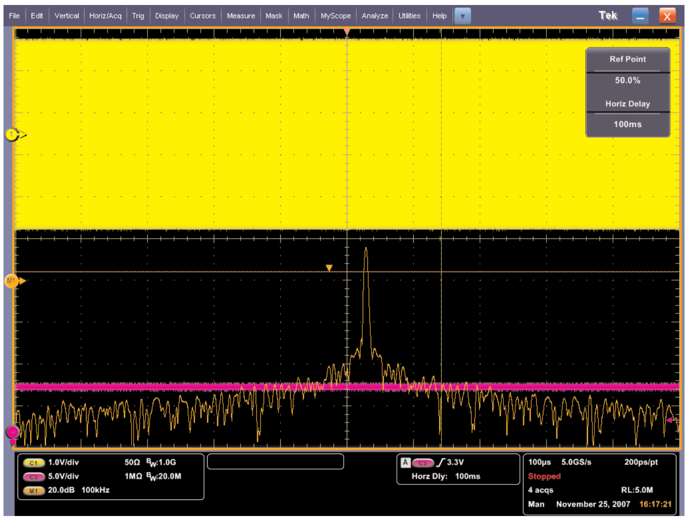

Figure 3.3. Signal and spectrum with 100 milliseconds of delay after power amplifier startup.

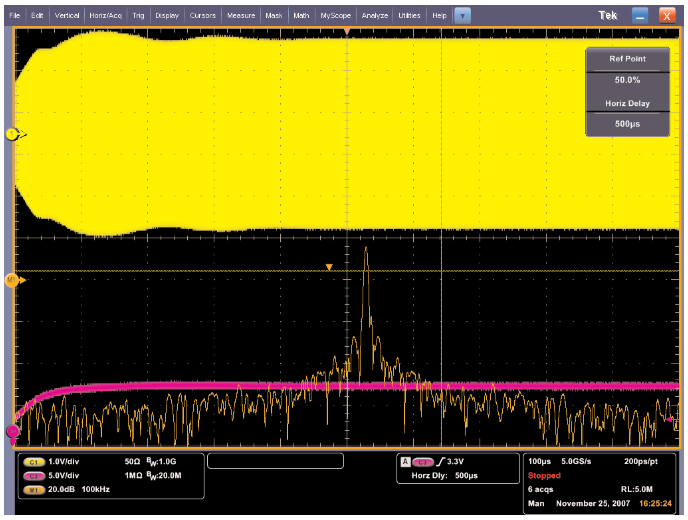

Figure 3.4. Signal and spectrum with 0.5 milliseconds of delay after power amplifier startup.

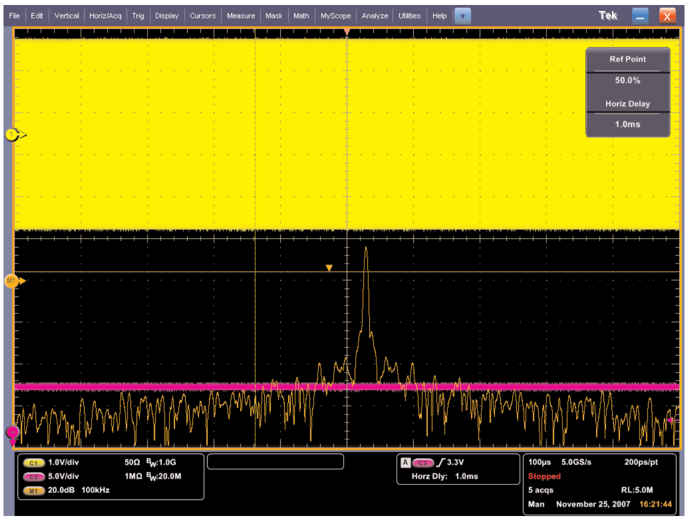

Figure 3.5. Signal and spectrum with 1 millisecond of delay after power amplifier startup.

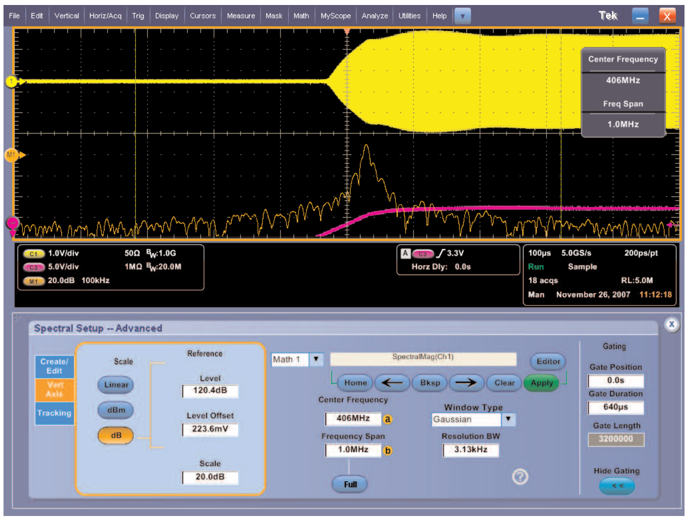

Figure 3.6. Setup screen for advanced spectrum analysis.

Using a 1 millisecond delay, the output signal shown in Figure 3.5 appears to be stable and reliable. The spectrum signal (orange trace) and the output signal (yellow trace) look very much like those at 100 milliseconds in Figure 3.3. Thus, by this time, the signal and the spectrum are clean, so this delay is sufficient enough prior to starting the data transmission. It is possible that the time could be slightly shorter, but since the transmission itself is about 100 milliseconds in length, reducing the delay time by fractions of a millisecond will have minimal effect on the battery energy consumed.

By looking at the output spectrum of the transmitter in this example, we determined that with a 1 millisecond delay after powering the amplifier, the output had stabilized and the data could reliably be sent from the transmitter. The DPO7000 Series oscilloscope allowed us to set the time at which the spectrum was captured, thus the performance of the radio transmitter could easily be evaluated with different delays. From a series of spectrum captures we were able to quickly determine when the signal had stabilized.

Figure 3.6 shows the setup screen for the Advanced Spectrum Analysis feature of the DPO7000 Series oscilloscope. The Gating feature allows setting the delay from the trigger to the time when the spectrum is taken. The typical settings of center frequency, frequency span, resolution bandwidth, and level are also provided, thus the oscilloscope can provide extensive capabilities for many RF projects.

Summary

Utilizing specific measurement techniques, we were able to quickly and efficiently ensure cost-effective communications in your embedded designs. Whether you are working with wired or wireless interfaces, Tektronix can help you achieve your design goals and deliver reliable solutions to the market.

With the right measurement tools, such as the DPO7000 Series oscilloscope, you can confidently verify, characterize, debug and test your embedded designs. As shown in these examples, advanced software analysis capabilities automate and simplify many measurements for USB, Ethernet, and RF spectrum analysis. Tektronix comprehensive test and measurement portfolio also offers a wide range of support for many other standards and technologies to help meet your design needs.

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